

High-Performance, Space-Storable, Bi-propellant Program Status

By

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Abstract

Bipropellant propulsion systems currently represent the largest bus subsystem for many missions. These missions range from low Earth orbit satellite to geosynchronous communications and planetary exploration. The payoff of high performance bipropellant systems is illustrated by the fact that Aerojet Redmond has qualified a commercial NTO/MMH engine based on the high Isp technology recently delivered by this program. They are now qualifying a NTO/hydrazine version of this engine. The advanced rhenium thrust chambers recently provided by this program have raised the performance of earth storable propellants from 315 sec to 328 sec of specific impulse. The recently introduced rhenium technology is the first new technology introduced to satellite propulsion in 30 years. Typically, the lead time required to develop and qualify new chemical thruster technology is not compatible with program development schedules. These technology development programs must be supported by a long term, Base R&T Program, if the technology is to be matured.

This technology program¹ then addresses the need for high performance, storable, on-board chemical propulsion for planetary rendezvous and descent/ascent. The primary NASA customer for this technology is Space Science, which identifies this need for such programs as Mars Surface Return, Titan Explorer, Neptune Orbiter, and Europa Lander. High performance (390 sec) chemical propulsion is estimated to add 105% payload to the Mars Sample Return mission or alternatively reduce the launch mass by 33%. In many cases, the use of existing (flight heritage) propellant technology is accommodated by reducing mission objectives and/or increasing enroute travel times sacrificing the science value per unit cost of the program.

Therefore, a high performance, storable, thruster utilizing fluorinated oxidizers with hydrazine is being developed under NASA contract by TRW¹. Propellant hypergolicity is required with the performance goal of at least 380 sec, which is 65 sec better than the performance of (flight heritage) engines presently flying (315 sec). System analyses are used to determine the system penalty for the cryogenic, in-space storage of the fluorinated oxidizer. The use of fluorine is expected to be similar to LOX. These propellants also will satisfy planetary lander requirements that carbon not be introduced into the lander environment, falsely influencing the science goal of searching for the precursors of life.

Reference 1. Calvignac, J. and Honda, L, "Storable Thruster Technology Program – Mission Study", Proceedings of the 51st JANNAF Propulsion Meeting, Lake Buena Vista, FL, Nov. 19-21, 2002

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Background Considerations

- Bi-propellant systems are the largest bus system for many missions
- Advanced Rhenium thrust chambers have raised performance of Earth storable propellants (MON-3/N₂H₄) from 315 to 328 seconds of specific impulse, becoming the benchmark to beat
- Program in 90's to develop space storable (LOX/N₂H₄) engine at 350 seconds fails to gain mission acceptance due to component penalties for handling cryogenics and helium pressurization penalty for cryogenics – 350 seconds was not enough performance for a cryogen
- Program to develop F2/N₂H₄ engine at 380 seconds begun in 2001 with TRW
- Key to higher performance of space engines is not more energetic propellants but lower molecular weight in the plume – More film cooling is required with energetic propellants resulting in combustion losses
- Lead time to qualify new thruster technology is not compatible with program development schedules and must be supported by the long term, Base R&T Program at NASA Glenn

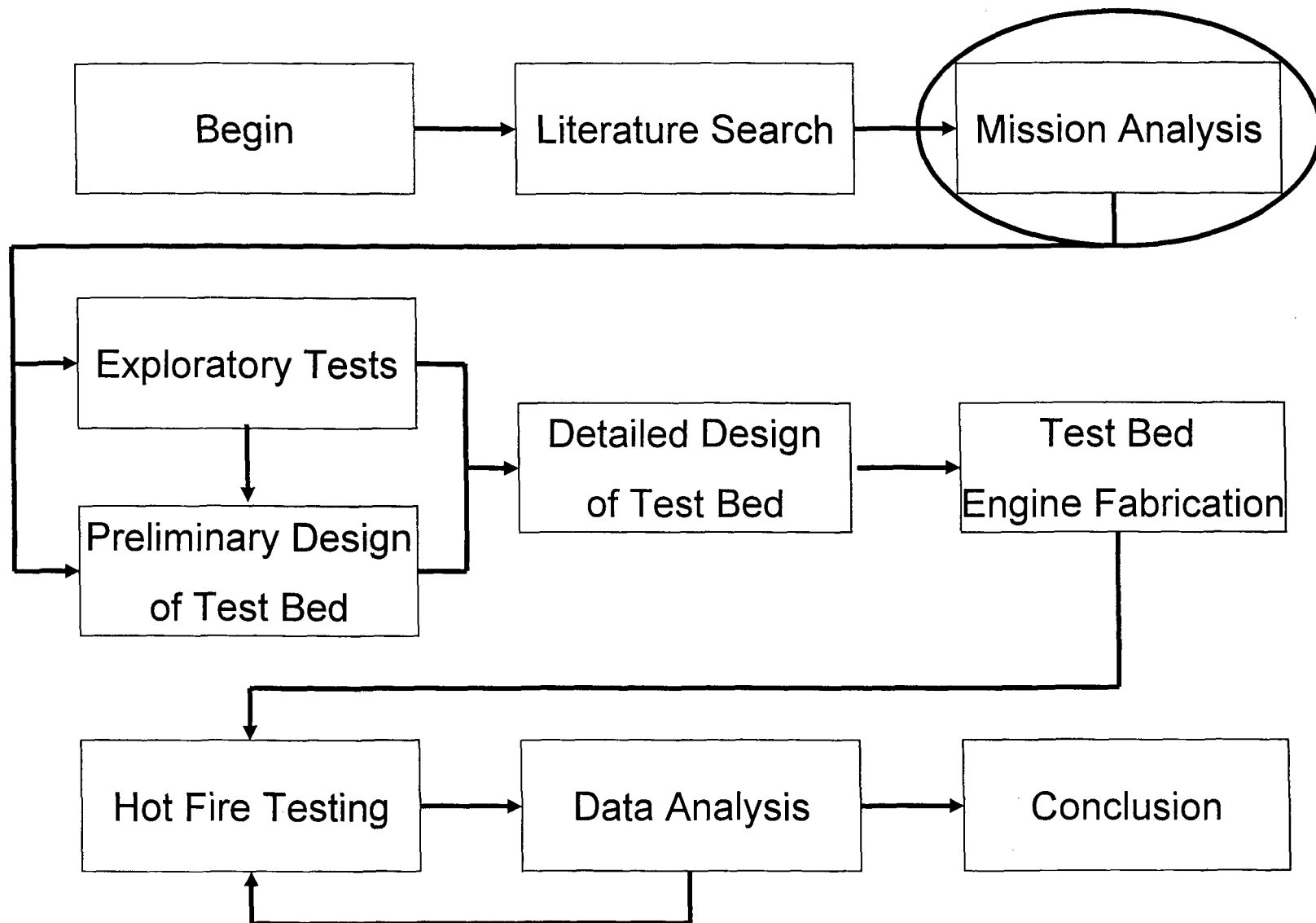
Relevance Considerations

- Primary NASA customer for this technology is Space Science
- High delta-V missions may be enabled
- Combined electric propulsion/chemical propulsion/aero-braking advocated to optimize mission constraints: Electric for transfer orbits, Chemical in gravity wells near planets to convert flybys to orbital missions, aero-braking to reduce propellant mass
- Existing (Flight heritage) technology is generally used by mission planners by reducing mission objectives and/or increasing enroute travel times
- Hypergolic propellants are needed for reliability
- F2/N2H4 propellants satisfy lander requirements that carbon not be introduced into the lander environment

Product Development Schedule

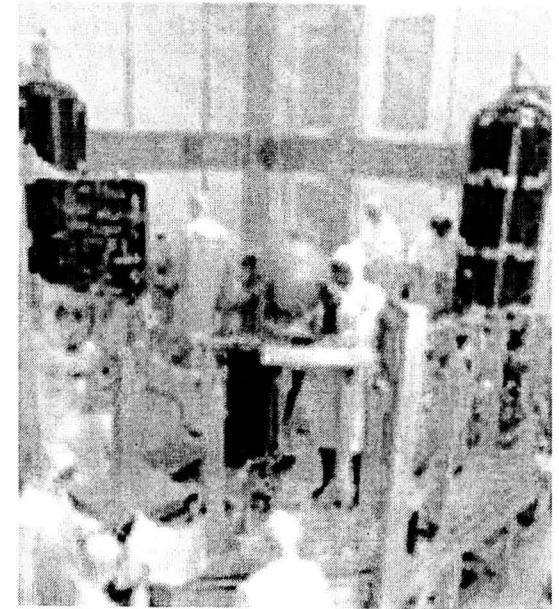
Milestones/ Product	Quarter	FY
Contract with TRW initiated for F2/N2H4 thruster	3rd	01
Mission analysis complete for F2/N2H4 propellants	1st	02
Engine concept downselect	1st	03
Material compatibility tests	3rd	03
Preliminary Design Review	4th	03
Critical Design Audit	4th	04
Component fabrication/performance tests	4th	05
Delivery of engine to NASA for performance tests	4th	06

TRW Program Plan



Mission Analysis

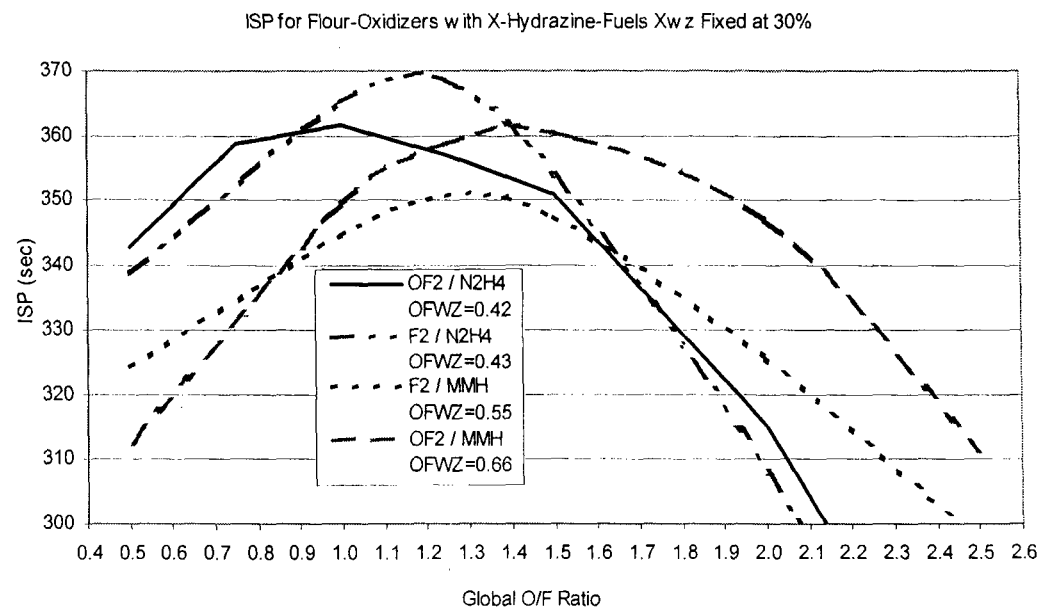
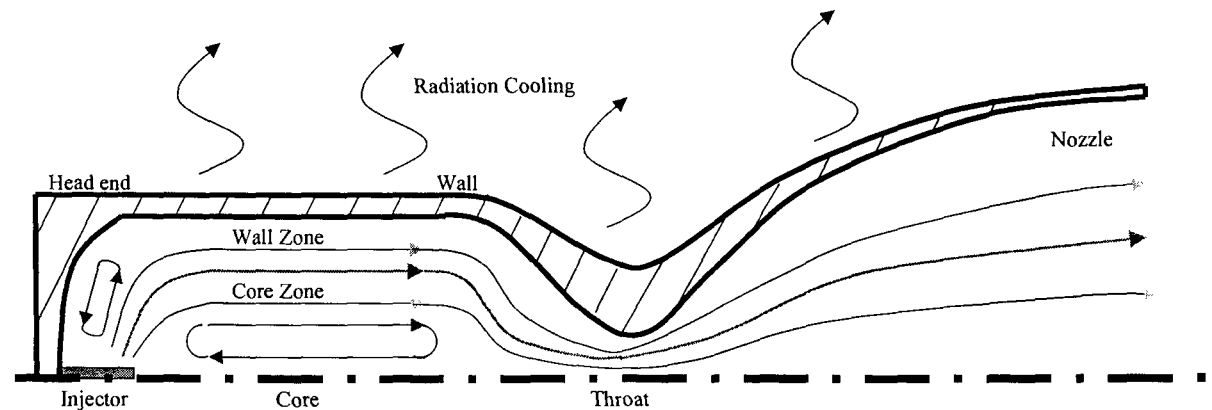
- Compare propellants based on:
 - Performance
 - Space-storable versus Earth-storable for each mission
 - Space-storable versus space-storable for a given thruster with TDK99
 - Safety
 - Logistics – availability, shipping, storage
 - Other - plume contamination, material compatibility, cost, risk, etc
- Derive design-to requirements for the engine
- Test bed



TRW Thruster Design

Pintle Injector

- TDK99 simulations for feasibility
- Based on 2-zone radiation cooled model, $P_c=110$ psia and $A_e=200:1$
- Nozzle not optimized
- Shows MMH and OF_2 have lower performance than HYD and F_2
- Performance goal to be achieved by increasing P_c to 200 psia and A_e to 350:1



Safety

Category	Cryogenic Oxidizers					Oxidizer	Fuels	
Formula	NF ₃	OF ₂	F ₂	FLOX	O ₂	N ₂ O ₄	N ₂ H ₄	CH ₃ N ₂ H ₃
Physical Properties								
Molecular Wt.	71	54	38	NA	32	92	32	46
Freezing Point	-341°F -207°C	-370°F -224°C	-363°F -220°C	NA	-361°F -218°C	12°F -11°C	35°F 1.4°C	-62°F -52°C
Boiling Point	-201°F -129°C	-230°F -145°C	-307°F -188°C	-305°F -187°C	-297°F -183°C	70°F 21°C	236°F 113°C	190°F 88°C
Liquid Density at NBP	96lb _m /ft ³ 1.54g/cc	96lb _m /ft ³ 1.53°g/cc	94lb _m /ft ³ 1.51g/cc	90lb _m /ft ³ 1.44g/cc	72lb _m /ft ³ 1.15g/cc	90lb _m /ft ³ 1.43g/cc	63lb _m /ft ³ 1.01g/cc	54lb _m /ft ³ 0.87°g/cc
Toxicity								
OSHA TWA	10	0.05	0.1	NA	NA	3	0.1	0.2
IDLH	2000	0.5	25	NA	NA	50	80	20

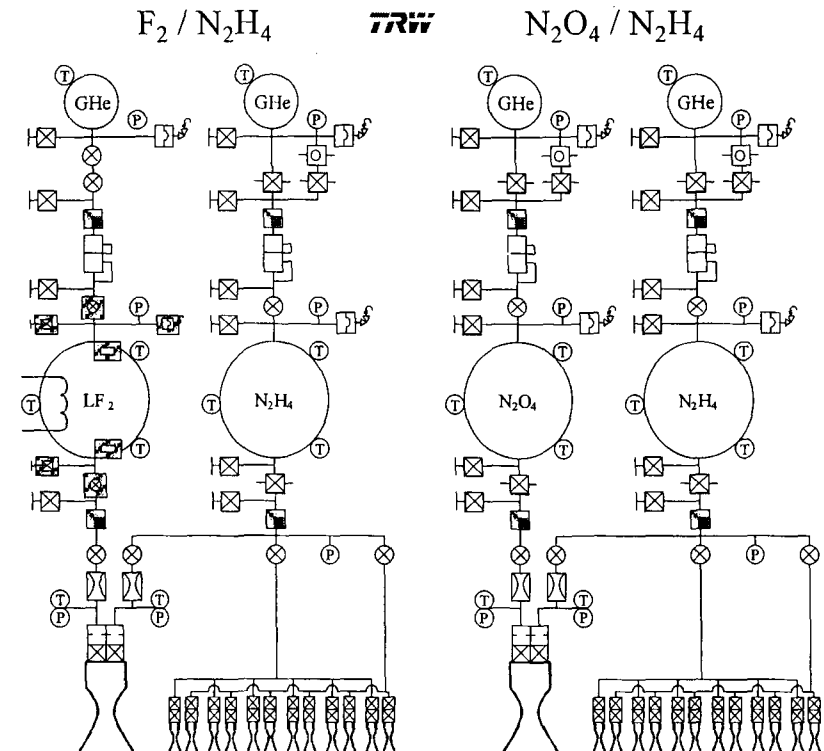
(IDLH) Immediately Dangerous to Life or Health Concentration ppm

(TWA) Time Weighted Average Exposure Limit 8 hour ppm

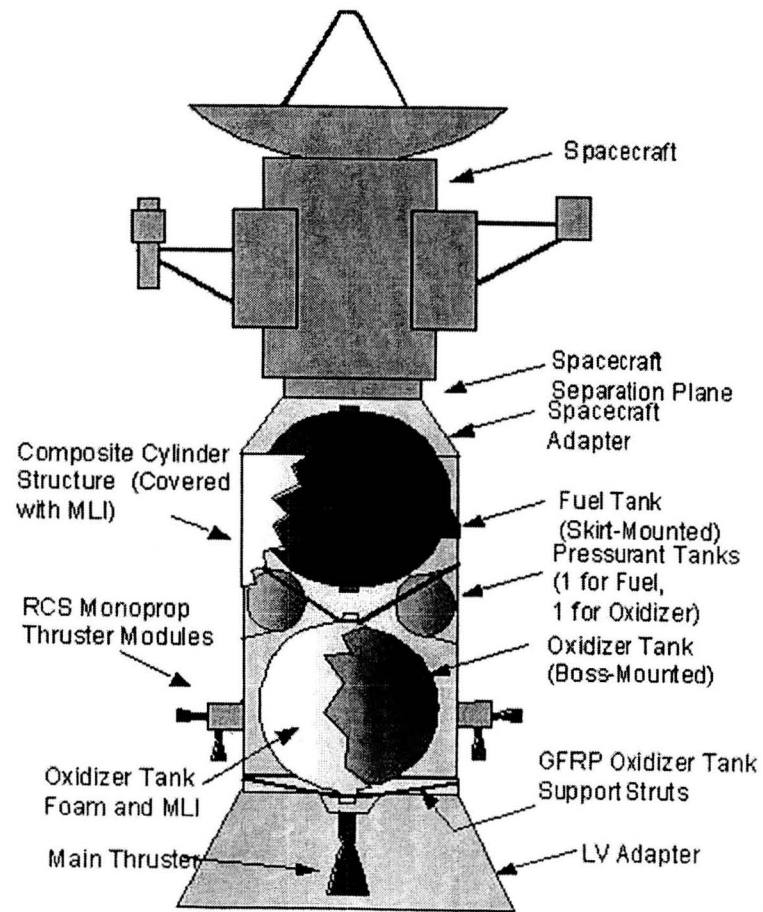


System Performance

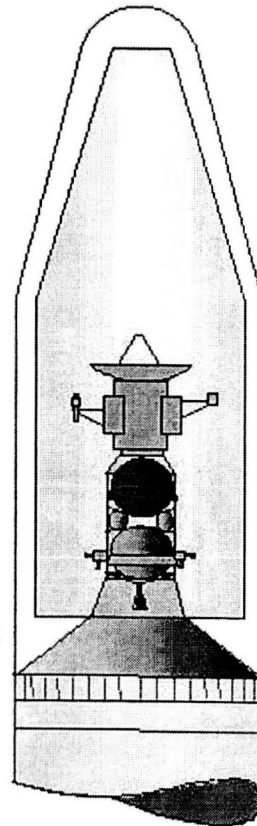
- Design of propulsion system scaling model based on TRW experience
- Estimated system properties like tank volume, system mass, insulation, cryo-coolers, etc.
- Calculated earth-storable propellant and space craft masses
- Compare to NASA-JPL results
- Replace oxidizer with space-storable propellant and compare launch/payload mass for a given launch vehicle and total launch weight for a given payload



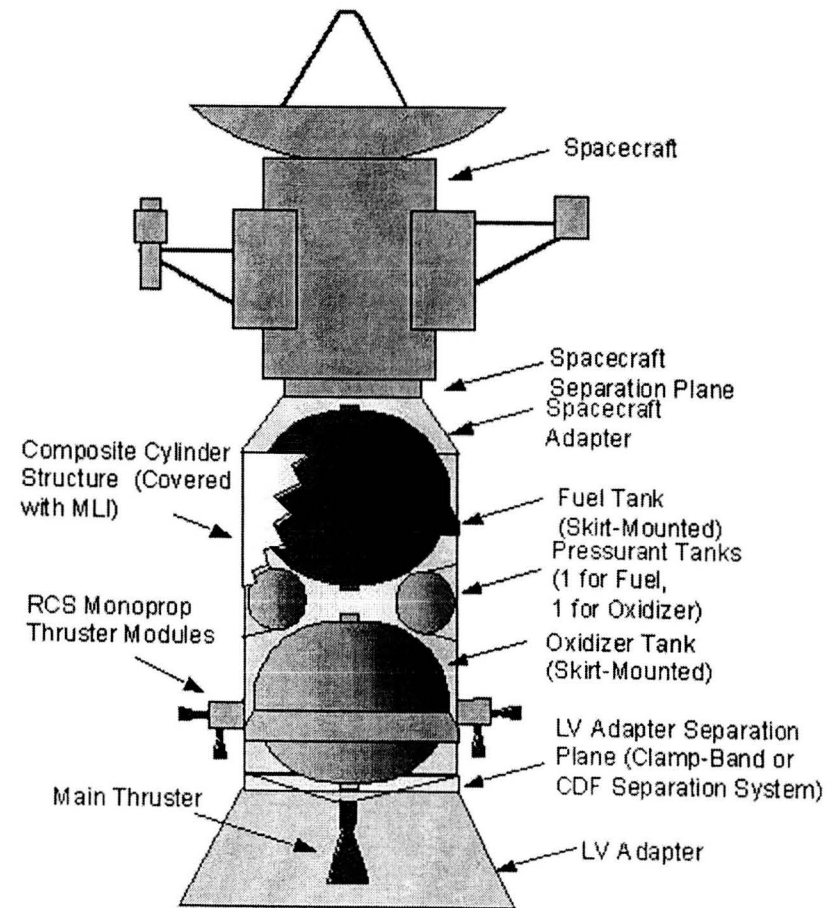
Propulsion System Concept



Space Storable Propellants



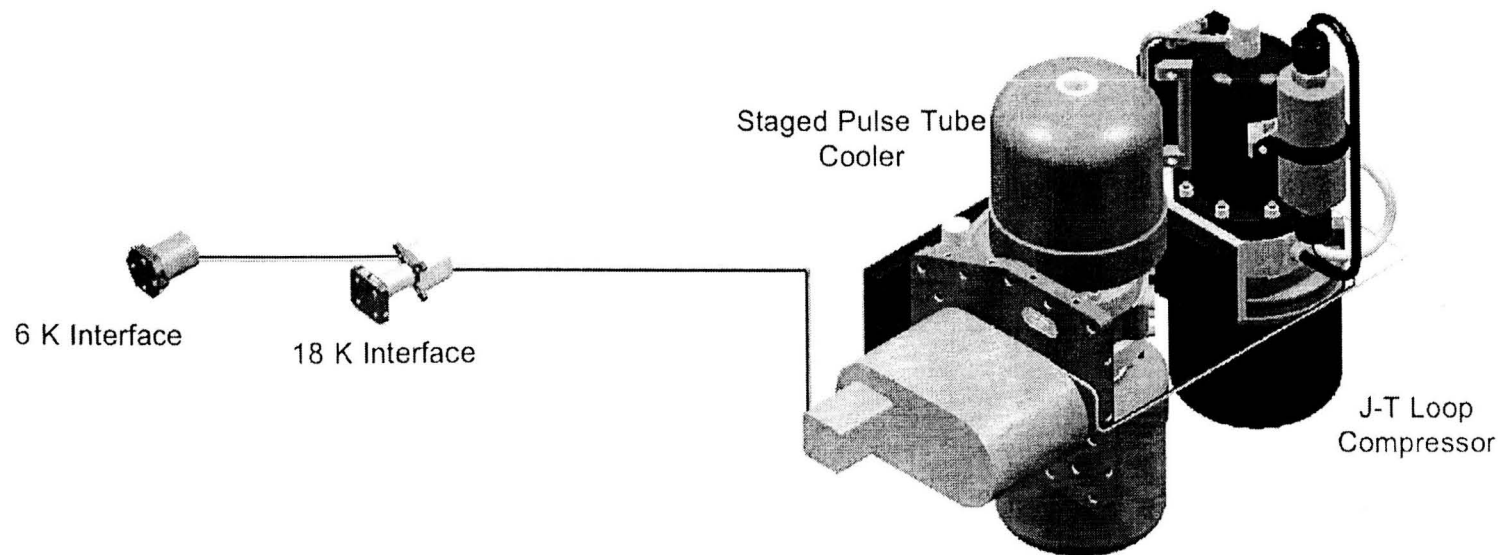
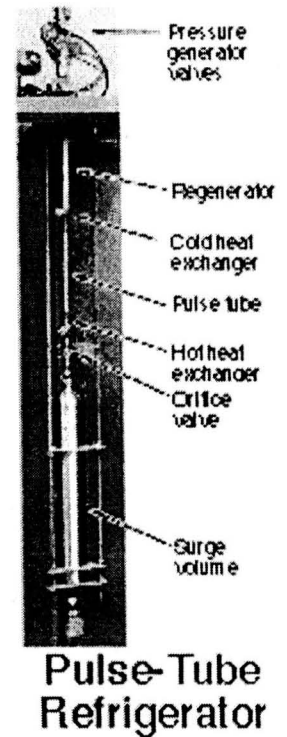
Delta IV 4-m PLF



Ground Storable Propellants

Cryo Coolers

- Cryo-coolers increase advantage of space-storable propellant
 - Cooling similar to LOX
 - Allow zero boil-off of cryogenic propellants
 - Reduce total mass of system from insulation
 - Efficient and allows temperatures < 10 K



Mission Analysis Results - 390 Isp

Mission Planning (final stage details)		Geo	Mars Sample Return	Titan Explorer w A/C	Neptune Orbiter	Europa Lander (medium)	Europa Lander (heavy)
NTO / HYD Baseline ISP = 325 sec	Payload (kg)	2010	247	848	543	669	1552
	Delta V (m/s)	1805	3800	1850	2200	2300	2300
	Stages	H2/O2 NTO/HYD	H2/O2 NTO/HYD	NTO/HYD HYD	H2/O2 NTO/HYD	H2/O2 NTO/HYD	H2/O2 NTO/HYD
	Propulsion System Weight (kg)	223	151	155	124	143	252
	Propellant Weight (kg)	1701	979	1227	698	896	1989
	Total Launch Weight (kg)	3934	31000	2786	10900	5834	12654
Advanced Space Storable Max Payload ISP = 390 sec	Payload (kg)	2225	506	938	615	763	1778
	Stages	H2/O2 F2/HYD	H2/O2 F2/HYD	F2/HYD HYD	H2/O2 F2/HYD	H2/O2 F2/HYD	H2/O2 F2/HYD
	Propulsion System Weight (kg)	218	214	191	137	157	265
	Propellant Weight (kg)	1480	1295	1069	612	788	1749
	Total Launch Weight (kg)	3934	31000	2786	10900	5834	12654
	Payload Improvement	11%	105%	11%	13%	14%	15%
Advanced Space Storable Min Launch ISP = 390 sec	Payload (kg)	2010	247	848	543	669	1552
	Stages	H2/O2 F2/HYD	H2/O2 F2/HYD	F2/HYD HYD	H2/O2 F2/HYD	H2/O2 F2/HYD	H2/O2 F2/HYD
	Propulsion System Weight (kg)	220	148	181	130	147	241
	Propellant Weight (kg)	1344	711	984	548	698	1532
	Total Launch Weight (kg)	3540	20729	2565	9792	5145	11026
	Launch Weight Improvement	10%	33%	8%	10%	12%	13%
Minimum Thrust Level (lbf)		127	111	92	53	68	150

Summary

- Mission Analysis
 - Technology (cryo-coolers, etc) increase advantages
 - Space-storable can have either a 7 to 105% larger payload capability or a 6 to 33% lower launch weight
 - Space-storable enables more missions like MSR, saves cost and/or increases scope on others
 - More demanding missions benefit more from space-storable propellant
- Performance
 - F_2 with hydrazine has higher performance than other combinations
 - 380 seconds of Isp is reasonable goal
- Safety
 - F_2 similar to NTO and hydrazine and much safer than OF_2